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An indicator approach to industrial sustainability assessment: The case of China's Capital Economic Circle

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ABSTRACT

While industrial sector has long been the economic engine of China's Capital Economic Circle (CEC) including Beijing, Tianjin, and Hebei province, the consequences of its rapid expansion such as environmental degradation and social concerns are attracting exceptional attention. In recent years, policies and measures are largely applied to industrial sector of the CEC to find out a sustainable pathway. However, the sustainable development performance is lacking in scientific evaluation. To comprehensively understand the status quo of industrial performance under the pressure of climate change adaptation and mitigation, this study establishes an evaluation framework of sustainable performance for industrial sector of the CEC, synthesizing the economic, environmental and social pillars. Particularly, we use global principal component analysis (GPCA), a dynamic multi-criteria decision making model, to assess the progress of industrial performance in each region from a time series perspective. We find that industrial sectors in all three regions show good trends of sustainable development during 2009–2015. Among them, the industrial sector of Tianjin performed the best and maintained the best improving status because of its positive performance on innovation, employees' benefits, and economic structure. The industrial sector in Beijing had medium performance but it had outstanding advantages on social dimension for its high proportion of R&D employment with high income level. Hebei's industrial sector performed the worst for its relatively lower energy efficiency and heavy industry-based economic structure. The innovation-driven development mode in Beijing and Tianjin provides a direction for Hebei's industrial sectors.

1. Introduction

In response to the excessive exploitation of natural resources globally, the growing crisis of environmental pollution, and vast social inequality, the idea of sustainable development has been introduced and incorporated into several levels of the society (Waas et al., 2014). According to the Brundtland Report (WCED, 1978), sustainable development was defined as "the development that meets the needs of the present generation, without compromising the ability of future generations to meet their own needs." Guided by this idea, China proposed a sustainable development strategy in the China Sustainable Development Report (CAS, 1999) and promised to strive to develop it in an efficient manner with minimum environment cost. China's sustainable development strategy is used to not only guide the country-level economic development but also the sector-specific development progress. When sectors gradually adopt sustainable development, the whole society achieves the goal of sustainable development strategy. It is of great significance for governments and scholars to discuss approaches and pathway towards a sustainable development of industrial sector in China, particularly in the Capital Economic Circle (CEC) that includes Beijing, Tianjin, and Hebei province. The first reason is that sustainable development is the strategic direction for the CEC; and the second reason is that industrial sector is the pillar of regional economy, which significantly impacts economic, environmental, and social dimensions.

1.1. An overview of the industrial sectors in Beijing, Tianjin and Hebei

The CEC was formed considering the background of sustainable development strategy. During the transformation process to the

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sustainable development mode, industrial sector of each region in CEC gradually adjusted to its new functional orientation. As a scientific and technological innovation center, Beijing has highlighted knowledge and green economies, and has attempted to optimize the economic structure by vigorously developing the service sector and reducing the proportion of the industrial sector. Considering Tianjin, it is designed to be a nationwide advanced manufacturing research and development (R&D) base to ensure that the advanced manufacturing industries, such as electronic information, as well as certain strategic emerging industries, such as aerospace, biomedicine, energy saving, and protection industries are given priority to develop. Hebei continues to encourage traditional industries, in order to develop as a new industrial base and undertake the transformation of scientific and technological achievements created by Beijing and Tianjin.

Industrial sector of the CEC significantly impacts economic, environmental, and social dimensions. It is the pillar of regional economy, accounting for a large proportion of the regional gross domestic product (GDP). In comparison to the end of the 11th Five-Year Plan, the industrial value added (IVA) at constant prices in each region significantly improved. For example, in 2010, the IVA of Beijing, Tianjin, and Hebei was 264.8 billion yuan, 451.93 billion yuan, and 869.59 billion yuan, respectively; while in 2015, the IVA increased to 351.53 billion yuan, 845.94 billion yuan, and 1329.03 billion yuan, respectively, growing by 32.75%, 87.19%, and 52.83%, respectively. Also, industrial sector in each region has a different structural feature (see Fig. 1). Considering the industrial sector of Beijing, the top five highest IVAs were in the manufacture of automobiles (MA), production and supply of electric power and heat power (PSEH), manufacture of medicines (MM), manufacture of computers, communication, and other electronic equipment (MCC), and processing of petroleum, coking, and processing of nuclear fuel (PPCP). Their total IVA accounted for over 60% of the whole industrial sector. Considering Tianjin, the top five industries were smelting and pressing of ferrous metals (SPF), MCC, MA, manufacture of food (MF), and manufacture of raw chemical materials and chemical products (MRCMCP), whose total IVA accounted for approximately 50% of the whole industrial sector. Considering Hebei as the industry-specific IVA data could not be obtained, this study cannot describe the industrial structure. However, from the perspective of light and heavy industries, it is observed that majority of the IVA was derived from the heavy industry, accounting for over 75%. Although the IVA of the industrial sectors in the CEC region showed an increasing trend, the growth rate slowed down annually from 2010 to 2015, which is related to the increased IVA proportion of the tertiary industry. This means that the economy gradually turned to the tertiary mode, but the IVA proportion continued to account for over 15% in Beijing, and over 40% in Tianjin and Hebei province.

1.2. Challenges and policy guidance for industrial sector of the CEC

The industrial sector significantly affects the environment as it is the major consumer of natural resources and energy, and also the major emission source of waste. Sustainable development requires industrial sector not only to enhance energy efficiency but also to update its energy structure. The coal-based energy structure has caused several issues, particularly the recent air quality crisis. The fog and haze issue has become a nightmare for people living in the CEC. Although this issue was trigged by complicated factors, the combustion of non-clean coal and air pollution of the industrial sector are no doubt main reasons (Zhang et al., 2013). Governments have encouraged industrial sectors to enhance their energy efficiency and innovation level, which have inevitably changed the employment condition. For example, considering the industrial sector in Beijing, both the proportion and income of R&D employees have significantly increased owing to employment adjustment.

As one of the most important participants of the sustainable development strategy, industrial sectors of Beijing, Tianjin, and Hebei have experienced a variety of policy adjustments during the period of the 12th Five-year Plan. On the one hand, they have changed and upgraded their industrial structure based on their own function of promoting coordinated development; and on the other hand, the policy of reducing excessive industrial capacity requires the industrial sector, particularly the iron-steel, machinery, light, building materials, and electronic industries to control new capacity and eliminate backward capacity. In parallel, the State Council released the *Plan for the Transformation and Upgrading of Industrial Sector (2011–2015)*. The plan emphasized on the whole industrial sector to develop on the basis of five features, namely being innovation-driven, highly-efficient, environment-friendly, and considering people's livelihood benefit and endogenous growth, in order to continuously enhance the industrial sector's core competitiveness and sustainable development capacity (The State Council Of China, 2011). The above political regulations have a complicated impact on the economic growth, resource usage, and social employment structure of the industrial sectors in the CEC region.

1.3. The contributions of this paper

However, the effects of above polices and regulations in practice have been rarely scientifically tested until now. In addition, it is

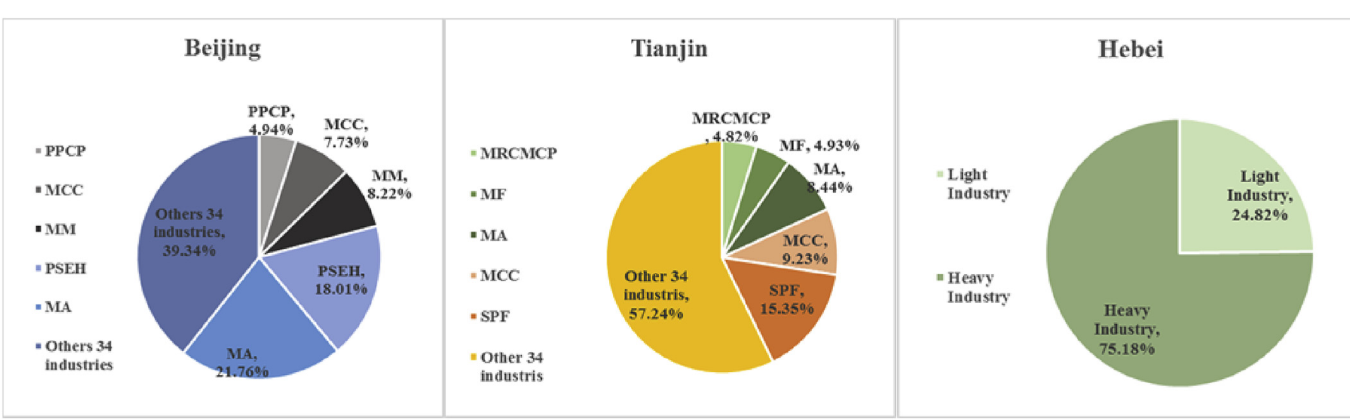

Fig. 1. Industrial structure in Beijing, Tianjin, and Hebei in 2015.

indeed significant to assess the sustainable development status of industrial sector of the CEC. Such assessments can provide a useful feedback for government decision-makers to observe the achievements and deficiencies that have to be further improved. Thus, focusing on the industrial sector of the CEC, this study aims to evaluate the sustainable development achievements by answering the following questions:

(1) How can we measure the status quo of the industrial performance?
(2) What tool can be used to assess sustainability progress of industrial sector in the CEC within the 12th Five-Year Plan?
(3) What are the reasons for positive or negative performances?

Aiming to undertake an indicator assessment of performance and progress of industrial sustainability, the global principal component analysis (GPCA), a dynamic multi-attribute decision making model is used in this paper. This work contributes to current literature on sustainable development assessment in several ways. First, an indicator-based assessment framework is built for the industrial sector of the CEC. These indicators are designed by fully considering the characteristics of the CEC's industrial sector and data availability. Based on the triple bottom line (TBL) that contained economic, social, and environmental dimension, the impacts scientific and technological inputs on sustainable development are also integrated into the indicator framework. Second, this work focuses on the dynamic assessment of sustainable development rather than only evaluating sustainability in a certain year. Through GPCA, the yearly sustainability progress of industrial sector in each region can be clearly demonstrated, reflecting different impacts of industrial transformation policy on each region of the CEC. Third, this paper not only assesses the comprehensive achievements of sustainable development but also discusses shortcomings from economic, social, and environmental dimensions and possible reasons.

This paper first introduces the background of the study, and discusses its significance and contribution. Further, an indicator framework for industrial sector-specific sustainability assessment is established by combining classic indicators in literature and related policies on industrial sector of the CEC (Section 2). Based on the assessment framework, the GPCA method is used to further evaluate the sustainable development achievements of the industrial sectors in the CEC region from 2009 to 2015 (Section 3). The assessment results are analyzed in Section 4. Finally, the policies are suggested and recommendations made based on the results (Section 5).

2. Indicators of industrial sustainability assessment in the CEC region

Since the concept of sustainable development was raised, governments and scholars progressed beyond monetary benefits and considered the development mode of a nation, an industry, and a corporate. Elkington (1997) provided an approach by proposing a framework called the triple bottom line (TBL) that contained three parts, namely economic, social, and environmental. The TBL theory encourages practitioners to evaluate development not only from an economic impact, but also the social and environmental impacts (Krajnc and Glavic, 2005; Mainali and Silveira, 2015; Valenzuela-Venegas et al., 2016).

Based on the TBL theory, we choose an indicator-based method to evaluate and compare sustainability of industrial sector in the CEC. The first task is to select appropriate indicators that should reflect the economic, social, and environmental performances of industrial sector. Global Reporting Initiative (GRI) designed a set of indicators that have provided references to many studies (Krajnc and Glavic, 2004; Zhou et al., 2012). However, the GRI indicator framework contains a great large number of indicators that could be used to assess sustainability at both micro-level and macro level. Considering the redundant information, the key indicators should perform comprehensive assessments without having to engaging unnecessary complex databases (Genovese et al., 2017). In order to translate and deliver concise, scientific and credible information to decision makers, the indicators are selected against the criteria identified by OECD (2002), that is, analytical soundness (*i.e.* the indicators should have theoretical basis), measurability (*i.e.* the data should be available, quantifiable and updated periodically), region coverage (*i.e.* data can be compared across regions), and ability to describe sustainability performance of industrial sector in the CEC (Mainali et al., 2014).

Simultaneously, considering the requirements of Chinese 12th Five-year Plan, we present an indicator framework that also embodies the development goal of the industrial sector, which is innovation-driven, high-efficiency intensified, environmentally-friendly, and consider people's livelihood benefit and economic growth (Table 1). The indicators with a plus sign are positive indicators for which higher values are favorable, while the indicators with a minus sign are negative indicators in a favor of lower values.

Table 1
Indicators for industrial sustainability assessment in the CEC region.

	Economic	Social	Environmental
Economic Growth	IVA per GDP(+) IVA per capita(+) Labor productivity of total workers(+) the IVA growth(+)		
High-Efficiency Intensified	Energy intensity(−) Water intensity(−)		
People's Livelihood Benefit		Industrial employment contribution rate(+) Average annual income(+)	
Innovation- Driven	R&D intensity(+)	R&D employee rate(+) Enterprises with R&D activity rate(+)	
Environment -Friendly			Discharged waste water intensity(−) SO_2 emission intensity(−) NO_x emission intensity(−) Soot(dust) emission intensity(−) Hazardous solid waste(−) Inhalable particle(−) The rate of days with air quality standards in more than two(+)

Table 2
Time-series stereo data table.

	t_1	t_2	…	t_p
	$f_1,f_2, \ldots,f_m$	$f_1,f_2, \ldots,f_m$	…	$f_1,f_2, \ldots,f_m$
A_1	$x_{11}(t_1), x_{12}(t_1), \ldots, x_{1m}(t_1)$	$x_{11}(t_2), x_{12}(t_2), \ldots, x_{1m}(t_2)$	…	$x_{11}(t_p), x_{12}(t_p), \ldots, x_{1m}(t_p)$
A_2	$x_{21}(t_1), x_{22}(t_1), \ldots, x_{2m}(t_1)$	$x_{21}(t_2), x_{22}(t_2), \ldots, x_{2m}(t_2)$	…	$x_{21}(t_p), x_{22}(t_p), \ldots, x_{2m}(t_p)$
…	…	…	…	…
A_n	$x_{n1}(t_1), x_{n2}(t_1), \ldots, x_{nm}(t_1)$	$x_{n1}(t_2), x_{n2}(t_2), \ldots, x_{nm}(t_2)$		$x_{n1}(t_p), x_{n2}(t_p), \ldots, x_{nm}(t_p)$

The indicators in economic, social and environmental dimensions will be elaborated separately in the following sub-sections.

2.1. Indicators in economic dimension

The nature of sustainable development requires economic development to be maintained by taking social and environmental impacts into consideration. Economic development remains the most important goal of industrial sector, particularly in the developing countries. The GRI guidelines define economic sustainability as "*an organization's impacts on the economic circumstance of its stakeholders and on economic systems at the local, national and global levels*" (GRI, 2002). Indicators of economic dimension should cover industrial performances of benefit, resource usage efficiency (Garbie, 2014), and cost. Specifically, IVA growth (Vithayasrichareon et al., 2012) and IVA per capita (Voces et al., 2012) can directly reflect the benefits of industrial sector. Moreover, the contribution of industrial sector to regional GDP is also important for sustainability assessment, which is measured by IVA per GDP (Shen et al., 2015). In terms of resource usage efficiency, labor productivity of total workers (Kopacz et al., 2017), energy intensity, and water intensity are selected as indicators. Referring to the cost performance in previous literature, operational cost performance is often used for the sustainable assessment at the micro-level (Abdul-Rashid et al., 2017), which cannot be measured at the industrial level. Therefore, combining the innovation requirement of industrial sector, R&D intensity (Li et al., 2012; Joung et al., 2013) is selected as an indicator to reflect cost performance. Based on literature in this domain, the following seven indicators are included in the economic dimension:

(1) IVA per GDP: IVA of the industrial sector/region GDP; reflecting the position and status of the industrial sector in the regional economy.
(2) IVA per capita: IVA/regional population
(3) Labor productivity of total workers: IVA/total regional employment; reflecting the comprehensive performance of the technological level, management, skill level, and labor enthusiasm.
(4) IVA growth: (IVA of the current year-IVA of the previous year)/IVA of the previous year; reflecting the increasing speed of IVA.
(5) Energy intensity: energy consumption/IVA; reflecting the economic benefits of energy use.
(6) Water intensity: water consumption/IVA; reflecting the economic benefits of water use.
(7) R&D intensity: R&D expenses/main business income; reflecting the efforts of the industrial sector on scientific and technological innovation.

In the context of the CEC, IVA per GDP, IVA per capita, labor productivity of total workers, and the IVA growth reflect the level at which the industrial sector meets the economic growth aspect; energy and water intensities reflect whether the industrial sector has developed in a high-efficiency intensified manner; R&D intensity reflects the innovation-driven requirement.

2.2. Indicators in social dimension

The social dimension is concerned with the attitudes of companies toward the treatment of its employees, which is usually measured by salary and employment rate. Thus, industrial employment contribution rate (Sureeyatanapas et al., 2015) and average annual income (Sharma and Balachandra, 2015; Buys et al., 2014) are selected as indicators of the social dimension. Meanwhile, the social performance should also include the impacts of industrial sector on social system. In this paper, R&D employee rate (Lee and Zhong, 2015) and enterprises with R&D activity rate (Singh et al., 2012; Voces et al., 2012) are selected in order to reflect the role of industrial sector in driving the innovation development of the whole

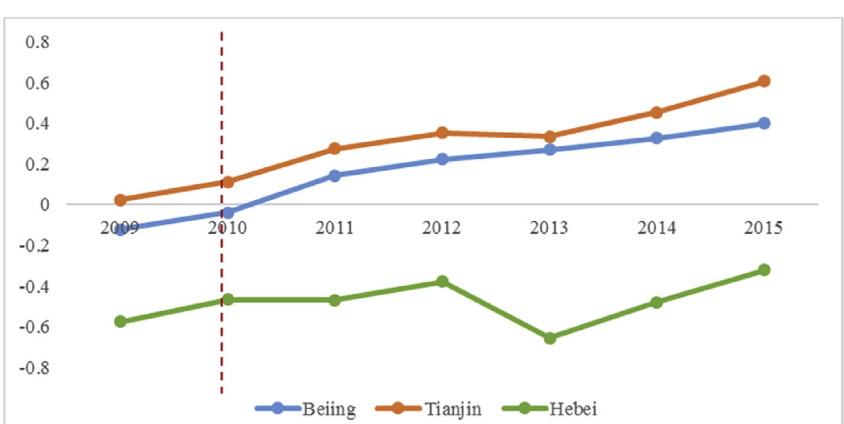

Fig. 2. Overall sustainable development score of the CEC's industrial sector (2009–2015).

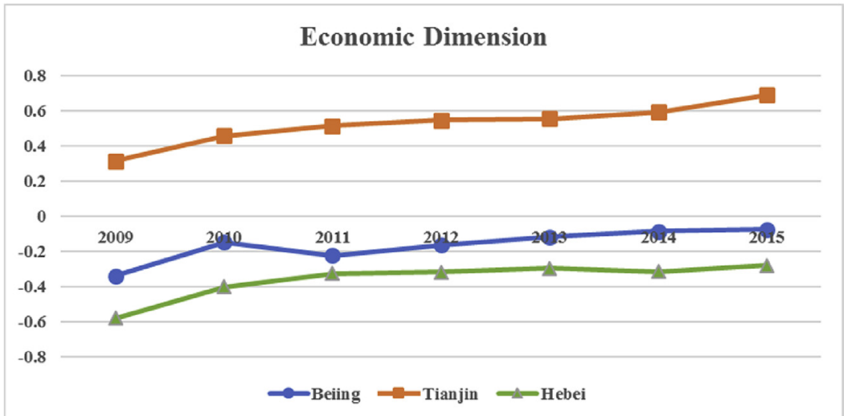

Fig. 3. Score of economic sustainable development of the CEC's industrial sector (2009–2015).

society. The social dimension includes the following four indicators:

(1) Industrial employment contribution rate: industrial employment/total regional employment; reflecting the contribution of industrial sector to social employment.
(2) Average annual income: this indicator reflects the income level of industrial employees.
(3) R&D employee rate: number of R&D employees of industrial sector/total industrial employment; reflecting the R&D employee demand of industrial sector.
(4) Enterprises with R&D activity rate: number of enterprises with R&D activities/regional total number of enterprises.

Among the four indicators, industrial employment contributor rate and average annual income reflect the requirement of people's livelihood benefit; while enterprises with R&D activity rate and R&D employment rate reflect the innovation-driven requirements.

2.3. Indicators in environmental dimension

Environmental sustainability is concerned with the impacts of industries on the environment. It reflects the environment-friendly requirement of the CEC's industrial sector. In this study, this dimension contains the following seven indicators: discharged water intensity (Yakovleva et al., 2012a, b), sulphur dioxide (SO_2) emission intensity (Long et al., 2016), nitrogen oxides (NO_x) emission intensity (Salvado et al., 2015), soot (dust) emission intensity (Bottani et al., 2017), and hazardous solid waste intensity(Feil et al., 2017) are the indicators reflecting waste discharged rate of the industrial sector; inhalable particles and the rate of days with good air quality reflect the impact of industrial coal consumption on regional air quality.

3. Methodology

The static PCA method has been widely used to evaluate objects at a certain point. The core idea of the static PCA method is to reduce the dimension, that is, to find fewer variables to describe the original data without losing considerable information. By linear changes, the original data is transformed into a set of pairwise linear independent variables with the total variance remaining unchanged. Assuming that the original data consists of n m-dimensional vectors, the variable matrix is$X = (x_1, x_2, ..., x_m)^T$. The goal of the static PCA is to find k new variables $(k < m)$ p_1,p_2, ...,p_k that can explain the information contained in the original data. While assessing sustainable development for the industrial sector of the CEC, it can be simplified as follows:

$$CS_t = \lambda(L)f_t + \varepsilon_t \tag{1}$$

CS_t represents the comprehensive score of the industrial sector

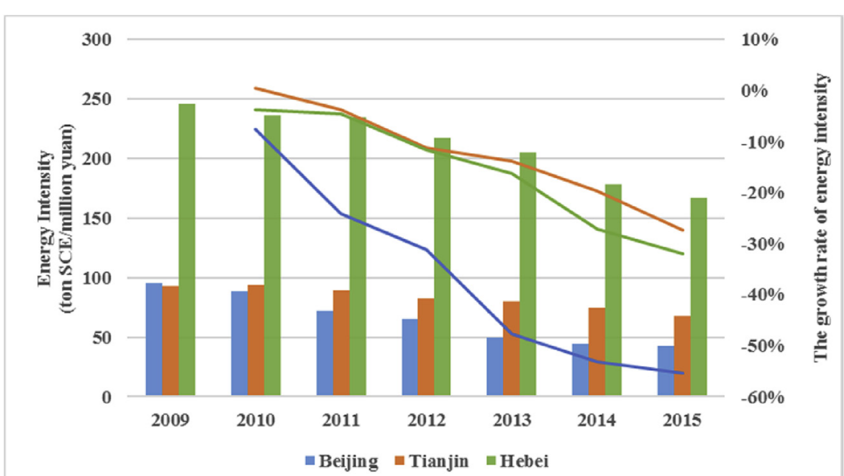

Fig. 4. Energy intensity of the CEC's industrial sectors (2009–2015).

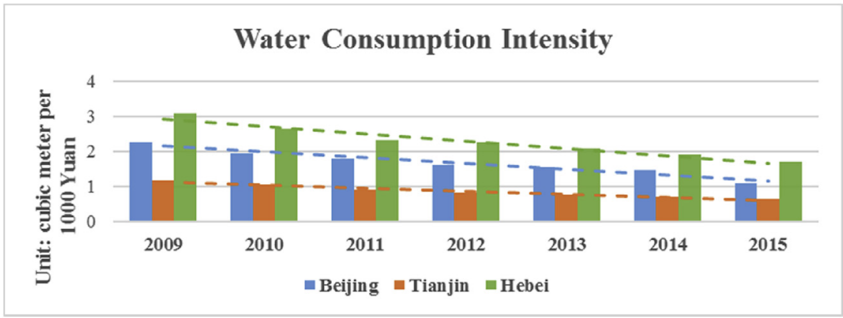

Fig. 5. Water consumption intensity in the CEC region (2009–2015).

in each region at time t; f_t is the vector of the variables $(f_1, f_2, \ldots f_{18})$ representing 18 indicators; and $\lambda(L)$ is the coefficient matrix that is estimated by the static PCA model. Rather than using a regression analysis, the estimation generates the matrix of unknown weights by using an orthogonal transformation. This process converts original data to a group of new vectors, namely the principal component, in a manner that they inherit the maximum possible variance from the original data. Each principal component is a linear combination of the original variables.

The static PCA is only used for cross-section data formed by assessment objects and indicators without taking time series into consideration. However, as sustainable development is a dynamic and comprehensive concept, the sustainability evaluation of the CEC's industrial sector should not only focus on the development state at a certain time point, but also consider the status change with time. In this paper, assessment involves information from both TBL dimensions and the trans-temporal changes of each dimension. Considering the CEC region, there is a similar cross-section data table with the same objects and indicators annually. If the static PCA method is applied separately for each cross-section data table, the results cannot be compared as different cross-section data as different times have their own specific principal component planes. To assess the three-dimensional dynamic data system, the GPCA method is applied.

The idea of GPCA method is to obtain the overall performance of evaluation object in the time range by conducting time series analysis on the new indexes formed by static PCA of evaluation object. The assessment of sustainable development of the CEC's industrial sectors can be simplified into Eq. (1) and Eq. (2).

$$F_t = \psi(L)F_{t-1} + \eta_t \tag{2}$$

$\psi(L)$ is the structural function describing trans-temporal change of each factor. ε_t in Eq. (1) and $\eta_t$in Eq. (2) are the independent error terms, which are assumed to be identical and independently distributed. $\psi(L)$ is assumed independent of $\lambda(L)$ (Zhang et al., 2015).

Before using GPCA method, a time-series stereo data table needs to be established. In order to solve the issues of unity and comparability, the cross-section data at different times should be integrated into the unified sequential three-dimensional data table, which is further analyzed by the static PCA. A plane data table consists of different indicators of multiple evaluation table. Considering the time development, each plane data table at different time point is stacked in sequence, which is called the time-series stereo data table. The essence of the time-series stereo data table is to extend the two-dimensional data in the time dimension, consisting a three-dimensional data of evaluation objects, indicators, and time series. As shown in Table 2, in the time-series stereo data table, t_p $(p=1,2, \ldots,7)$, A_n $(n=1,2,3)$ and x_m $(m=1,2, \ldots,18)$ represent the year, evaluation objects, and indicator, respectively. Thus, $x_{nm}(t_p)$ represents the indicator m's value of evaluation object n in p year.

After building the time-series stereo data table, it is necessary to carry out standardized processing to transform the indicators into the same scale because different indicators often have different measuring units. Meanwhile, the negative indicators should be converted to ensure the same trend as the positive ones. Thus, the transforming equation for positive indicators is as follows:

$$v^*_{ij}(t_p) = \frac{x_{ij}(t_p) - \min\limits_{i,j}\{x_{ij}(t_p)\}}{\max\limits_{i,j}\{x_{ij}(t_p)\} - \min\limits_{i,j}\{x_{ij}(t_p)\}}, \quad (i\in(1,2,\ldots,n), j\in(1,2,\ldots,m)) \tag{2}$$

For negative indicators, the equation is as follows:

$$v^*_{ij}(t_p) = \frac{\min\limits_{i,j}\{x_{ij}(t_p)\} - x_{ij}(t_p)}{\max\limits_{i,j}\{x_{ij}(t_p)\} - \min\limits_{i,j}\{x_{ij}(t_p)\}}, \quad (i\in(1,2,\ldots,n), j\in(1,2,\ldots,m)) \tag{3}$$

As a consequence, all the indicators are transformed to a range of 0 and 1 with the same trend. When the standardized values are closer to 1, they have a better effect on sustainable development.

The standardized data table is further analyzed by the GPCA method. When using the GPCA, certain improvements were made in this study. As the GPCA method is based on a pure mathematical derivation, it may generate principal components with no practical implications. In order to better observe the performance of CEC's industrial sector from economic, social, and environmental dimension, respectively, the GPCA method will be first applied within each dimension and then an index for a dimension is generated. Further, assuming that the economic, social, and environmental goals have equal effects on sustainable development, they have equal weights. The final index for sustainable development assessment is the average of the three dimensions.

All the data used in this paper are from the statistical yearbook, among which most of the economic data (i.e., IVA and regional GDP) and employment data (i.e., employment number) are from regional statistic yearbook[1] (i.e., *Beijing Statistic Yearbook (2015)*); the emission data (i.e., SO_2 emission) are from *China Statistic Yearbook on Environment (2010–2016)*; the R&D data (i.e., R&D employment number) are from *China Statistic Yearbook on Science*

[1] Beijing Statistic Yearbook (2010–2016) can be accessed from http://www.bjstats.gov.cn. Tianjin Statistic Yearbook (2010–2016) can be accessed from http://www.stats-tj.gov.cn. Hebei Statistic Yearbook (2010–2016) can accessed from http://www.hetj.gov.cn.

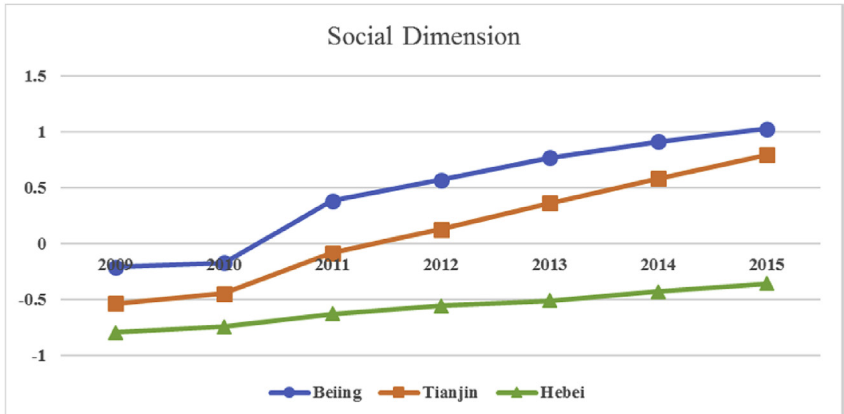

Fig. 6. Score of social sustainable development of the CEC's industrial sector (2009–2015).

and Technology (2010–2016)[2]; inhalable particles and the days with good air quality data are from the *WIND database*[3].

4. Results and analysis

By using the GPCA method, the economic, social, and environmental performances of sustainable development are assessed. The comprehensive assessment of sustainable development for the industrial sectors in the CEC region is achieved by calculating the average value of the three dimensions. The annual comprehensive score of the industrial sector in each region is shown in Fig. 2, where the value only represents the relatively positive or negative performance of sustainable development. The year of 2010 that is highlighted in Fig. 2 is the end of the 11th Five-Year Plan. It can be observed that generally, the industrial sectors in all three regions show good trends during 2009–2015. Among them, the industrial sector of Tianjin performed the best and maintained the best improving status during the 12th Five-Year Plan. While Hebei's industrial sector performed the worst, the performance in 2015 was even lower than that of Tianjin in 2009. The different performances among regions are caused by complex factors that will be explained from economic, social, and environmental dimension, respectively.

It should be noted that the sustainable development performance of the industrial sectors in both Tianjin and Hebei dropped in 2013. This was the time that the Chinese government raised the policy of reducing excessive production capacity, when a large number of backward production capacities were eliminated, particularly within the heavy industries in Hebei province. Meanwhile, the changes in economic, social, and environmental dimensions were complicated as some industrial enterprises moved from Beijing and Tianjin to Hebei. In order to further explore the effects of above changes, we discuss sustainable performance of industrial sector from each dimension's perspective.

Fig. 3 shows the economic dimension of sustainable development performance for industrial sectors of the CEC. The industrial sector of Tianjin had obvious advantages in this dimension. One of the reasons is that the industrial sector was the most important department of the local economic development in contrast to Beijing, where the IVA accounted for less in regional GDP as its position and role lay in the political and cultural center. The second reason is that in comparison to Hebei, Tianjin emphasized more on advanced manufacturing enterprises with more integrated scientific and technological inputs. Thus, the industrial sector performed better in the aspects of energy intensity, water intensity, R&D intensity, and labor productivity of total workers than that in Hebei.

Generally, during the period of the 12th Five-year Plan, energy efficiencies of the industrial sectors in the CEC region improved (see Fig. 4). Considering backward capacity gradually being eliminated and new energy-saving technologies being adopted, their energy intensities (energy consumption per IVA) show downward trends. Considering previous concerns of energy saving and emission reduction, the industrial sectors of Beijing and Tianjin had relatively more mature technologies and higher energy efficiencies. Hebei had the highest energy intensity, but as one of the provinces that reduced most excessive capacity, the energy intensity gaps with Beijing and Tianjin gradually narrowed. Particularly after 2011 and 2013, energy intensities show greater degrees of decline.

There are large gaps in energy use efficiency, emission reduction technology, and economic development among Beijing, Tianjin, and Hebei. Considering Beijing, energy intensity reduced from 88.17 to 42.47 ton Standard Coal Equivalent (SCE) per million yuan from 2010 to 2015, reduced at the rate of 51.8%. Energy intensity in Tianjin reduced from 93.58 to 67.63 ton SCE per million yuan from 2010 to 2015, reduced at the rate of 27.7%. In Hebei, the energy intensity reduced by 29.4%, from 236.47 to 166.62 ton SCE per million yuan. It can also be observed that energy efficiency of the industrial sector in Hebei was significantly lower than that in Hebei and Tianjin, which means that further adjustment of the energy structure and replacement of backward technology could be the appropriate direction in the future.

In terms of water resource use of the industrial sector, Tianjin had the highest usage efficiency with the lowest water consumption intensity (see Fig. 5). In comparison to 2010, the water intensity of Tianjin's industrial sector reduced by 41%, from 1.06 to 0.627 cubic meter per thousand yuan. Considering Beijing, the reduction rate of water intensity was 43.9%, which was the largest among the three regions. Although the industrial sector in Hebei province had the lowest water usage efficiency, its water intensity significantly reduced (36.2%) during the 12th Five-year Plan. The advantage of Beijing and Tianjin in terms of water consumption can be partly attribute to their innovation and application of water conservation technologies, as well as the strict requirements for the recycling usage of industrial water.

The performance of the social dimension is shown in Fig. 6. Being different from the economic dimension, the industrial sector in Beijing performed the best. With a higher proportion of R&D employees, the industrial sector of Beijing had a higher level of

[2] *China Statistic Yearbook on Environment (2010–2016)* and *China Statistic Yearbook on Science and Technology (2010–2016)* can be accessed from the Chinese CNKI database.

[3] The WIND database can be accessed by purchasing the terminal product of WIND.

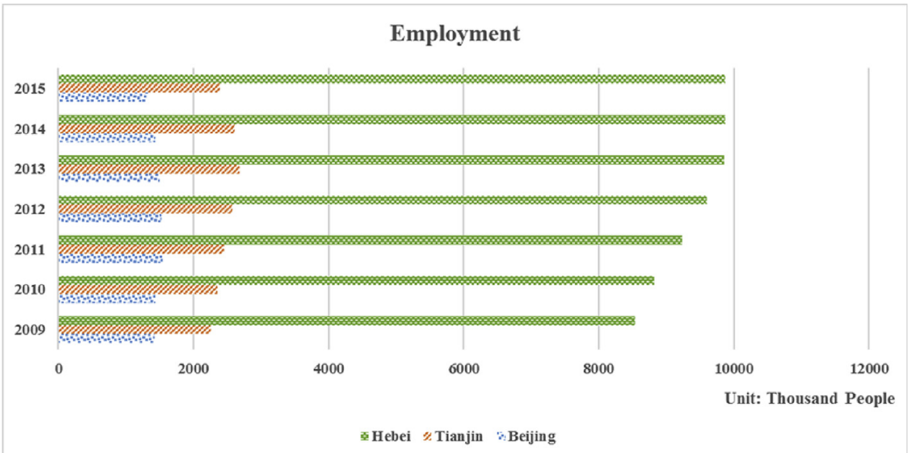

Fig. 7. Employment number of the CEC's industrial sector (2009–2015).

average annual income, resulting in its better performance in the social dimension. However, by strengthening the R&D investment and introducing well-paid R&D employees, the industrial sector of Tianjin gradually narrowed the gap. Considering Hebei, although employee benefits improved and innovative development was undertaken, there was a large gap in comparison to Beijing and Tianjin.

The employment number of the industrial sector accounts for approximately 20% of the total social employment in the CEC region. During the 12th Five-year Plan, the employment number of the industrial sector in Tianjin basically remained stable. Considering Beijing, employment decreased marginally, from 1.438 to 1.329 million people. However, considering Hebei, the employment number steadily increased before 2013, which was related to the industrial transformation from Beijing and Tianjin to Hebei. After 2013, considering the gradual implementation of reducing excessive capacity, the growth rate of industrial employment slowed down and the number remained stable (see Fig. 7).

Although the employment number of Beijing's industrial sector decreased, the average annual income significantly increased by 84.2% in comparison to 2010. Considering Tianjin, the average annual average was 74668.61 yuan in 2015 with a growth rate of 68.6%. The average annual income in Hebei increased the least, by approximately 59% (Fig. 8). Among the three regions, the income level of Beijing was the highest, followed by Tianjin and Hebei. This could be partially owing to the fact that Beijing had a higher level of economic development and consumption level, and partially due to the innovation feature of Beijing during the establishment of the CEC region, where a larger proportion of scientific employees with relatively higher income levels worked.

From the data we can observe that the industrial sectors of three regions have made some progress in economic development, energy and natural resource use, and employment. However, more indicators are required to check whether industrial development has met the requirements of sustainable development. As mentioned in the introduction section, industrial sectors of the CEC should develop on the bases of being innovation-driven, highly-efficient, environmentally friendly, and considering people's livelihood benefit and endogenous growth.

Performance in the environmental dimension was not very optimistic in comparison to the other two dimensions (Fig. 9). Excluding Beijing, the performances of Tianjin and Hebei in 2015 were worse than in 2010, that is, the end of the 11th Five-Year plan. The environmental dimension mainly includes industrial discharges and inhalable particles. China previously established strict standards for industrial emissions, and with technological progress, there was an annual reduction in industrial waste water, waste gas, and solid waste. However, from the original data, we suggest that

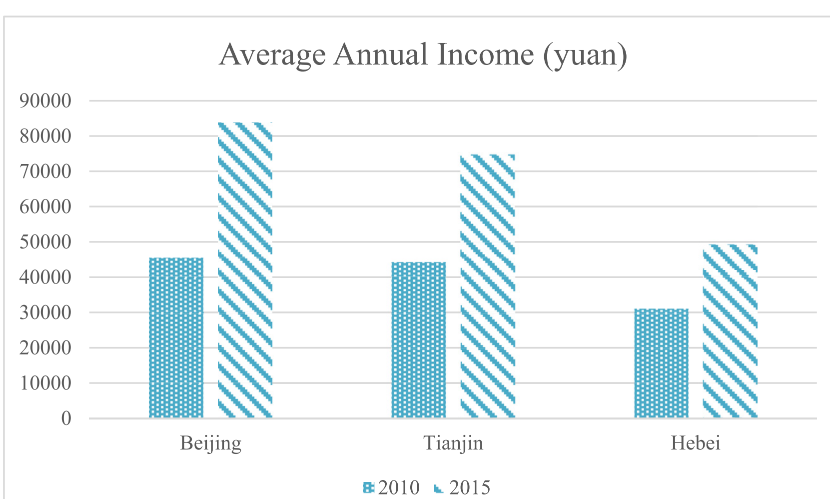

Fig. 8. Average annual income of the industrial sector in 2010 and 2015.

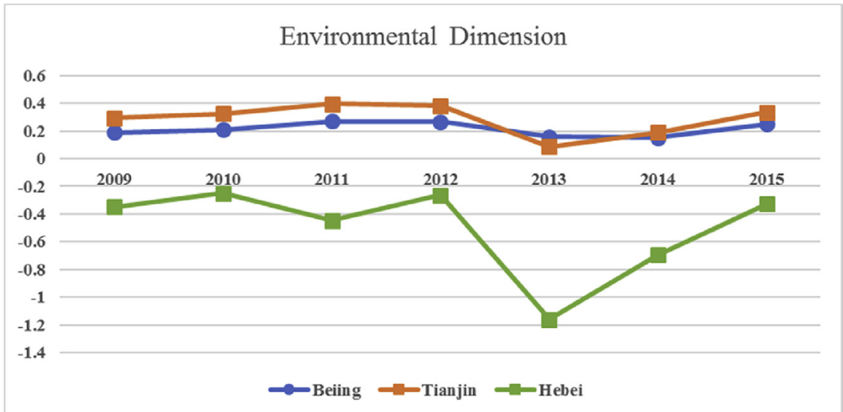

Fig. 9. Score of environmental sustainable development of the CEC's industrial sector (2009–2015).

poor environmental performance was largely due to the high concentration of inhalable particles and bad air quality caused by fossil fuel combustion. The results reflect that the energy structure needed to be further improved and the proportion of clean fuel increased.

In summary, relative to the end of the 11th Five-Year Plan, sustainable development performance of the CEC's industrial sector improved by the end of the 12th Five-Year Plan. Tianjin showed the best performance, particularly in the economic dimension. In addition, performance of the social dimension also improved. Beijing showed a better social performance for its large proportion of R&D investment and high-paid employees, showing the direction for Hebei to focus more on scientific and technological inputs during the industrial development process. All the three regions showed poor performance in the environmental dimension mainly owing to the issue of inhalable particles which was not appropriately solved.

In terms of the requirements raised in the *Plan for the Transformation and Upgrading of Industrial Sector*, industrial sector of the CEC basically achieved the goal of being innovation-driven, high-efficiency intensified, environment-friendly, and considering people's livelihood benefit and economic growth. In all the three regions, the innovative function was gradually being emphasized. With improvements in equipment and technologies, energy efficiency also improved during the period of the 12th Five-Year Plan. People's livelihood benefit increased, particularly for R&D employees. Considering the aspect of economic growth, with excessive and backward production capacity replaced, the economy became more stable and witnessed healthy development. The realization of the environment-friendly goal is a long-term process that depends on several aspects, including technology improvement and energy structure perfection.

5. Policy and inspiration

Based on the research results and requirements of the governments, policies are designed and suggestions are made for future sustainable development of the CEC's industrial sector.

The industrial sectors should strengthen scientific and technological investments, and enhance independent innovation capacity. In particular, when moving certain industries to Hebei from Beijing and Tianjin, technologies should also be introduced to initiate technology upgrade of the whole industry and related external industries. The Chinese government has emphasized on the innovation-driven mode as the direction of sustainable development. Achieving economic development through technological innovation also conforms to the requirements of endogenous growth of enterprises. As can be seen from the results, Beijing and Tianjin performed better because of their stronger industry-university-research cooperation and greater attractions of higher incomes and career prospects to talents with innovative knowledge. The results provide a direction for Hebei province to enhance innovation level. Hebei province should fully play the role of a government and create a nurturing atmosphere to encourage creativity of enterprises. Policies related to introducing talents and protecting achievements for innovations should also be perfected.

Governments should insist on adjusting the energy structure to enlarge the proportion of electricity in the final energy consumption. Energy efficiency should be further enhanced to reduce energy consumption. In order to achieve high-efficiency and environment-friendly mode of development, policies should be designed by considering both energy efficiency and resource utilization efficiency. Moreover, according to analysis results of this study, the concentration of inhalable particles has not reduced and the air quality has not been effectively improved, which is to some extent relevant to the coal-based energy structure. Therefore, Policies that promote the development of renewable energy should be implemented in order to reduce air and environmental pollution. We suggest the active development of policies in relation to resource and waste recycling to ensure that improved resource utilization efficiency can assist in reducing the demand for resources by the industrial sectors.

Requirement of people's livelihood benefits cannot be ignored during the sustainable development process of the industrial sector. Governments and enterprises should focus on the welfare of employees. In addition to the enhancement of income mentioned in this study, the issues of staff housing, medical, and insurance should also be settled appropriately.

6. Conclusion

Policies and measures are largely applied to the industrial sector of the CEC. In order to continuously enhance core competitiveness and sustainable development capacity, industrial sectors are required to develop on the basis of five features, namely being innovation-driven, highly-efficient, environment-friendly, and considering people's livelihood benefit and endogenous growth. This study establishes an indicator-based evaluation framework for sustainable performance of CEC's industrial sectors in order to synthesize the economic, environmental and social pillars. In particular, the global principal component analysis (GPCA), a dynamic multi-criteria decision model, is used to assess the progress of industrial

performance of each region during the 12th Five-Year Plan period.

The results show that generally, from 2009 to 2015, the industrial sectors in Beijing, Tianjin and Hebei province all showed good trends of sustainable development. Among them, the industrial sector in Tianjin performed the best and maintained the best improving status during the 12th Five-Year Plan period because of its obvious advantages in economic and social dimensions. Tianjin's industrial sector was gradually transforming into an innovation-driven and highly-efficient development mode and also considered employee's livelihood benefit. Beijing performed medium, where the industrial sector accounted for a relatively smaller proportion in the regional economic development but the energy intensity and water intensity was controlled better because of the more mature technologies. In parallel, the industrial sector in Beijing had a larger proportion of R&D employees with higher income, resulting in the outstanding performance in the social dimension of sustainable development. While for Hebei province, the situation was not very optimistic, although the industrial sector was the pillar of the provincial economy. Energy-intensity industries accounted for a larger proportion as the function position of Hebei province in CEC region was to undertake the transfer of the traditional manufacturing industries of Beijing and Tianjin. Coupled with the lower energy efficiency due to insufficient R&D investment, the sustainable development capacity of industrial sector in Hebei province was weaker. The achievements of Tianjin and Beijing can provide a direction for Hebei that attention should be to enhance the energy efficiency by strengthening the R&D investment, and attract more R&D employees by increasing the income level. For all three regions, the performances in the environmental dimension were not very optimistic in comparison to the other two dimensions. The poor environmental performance was largely due to the high concentration of inhalable particles and bad air quality caused by fossil fuel combustion. The most direct solution is to further improve the energy structure and increase the proportion of clean fuel.

Based on the results, we suggest that the industrial sectors should strengthen scientific and technological investment, and enhance independent innovation capacity, particularly in the industrial sector of Hebei province. And the policies should focus on both energy efficiency and resource utilization efficiency in order to achieve high-efficiency and environment-friendly development mode. In parallel, the requirement of people's livelihood benefits cannot be ignored.

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